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A ROME LABORATORY GUIDE TO BASIC TRAINING IN TQM ANALYSIS TECHNIQUES

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This report describes the basic analytical tools used in Total Quality Management (TQM); Process Flow Charts, Ishikawa Charts, Statistical Process Control, Histograms, Pareto Diagrams, Scattergrams and the Shewhart Cycle. For easier comprehension, a mythical scenario is used in which the tools are introduced to a willing, but untrained, manager (and to the reader) by a TQM specialist.

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FOREWORD

Total Quality Management (TQM) is a DoD initiative for continuously improving performance at every level, in every area of DoD responsibility. Implementing this philosophy will require a cultural change in the defense community. It will also require the intelligent use of appropriate analysis techniques.

This guide describes current techniques applicable to TQM analysis via a mythical scenario in which the techniques are introduced to an untrained but willing manager. Emphasis in this guide is on the practical use of the techniques. References are provided for the reader interested in mathematical derivations and proofs.

We hope this information proves helpful in accelerating the understanding and use of TQM.

Your comments and suggestions are welcome.

Anthony J. Feduccia
Chief, Systems Reliability
and Engineering Division

1 INTRODUCTION

Our scenario opens with Aristotle Hatt, the TQM guru of the (mythical) Air Force Psionics Laboratory frowning over the following memo:

Air Force Psionics Laboratory
Townsend AFB, NY

20 April 1989

From: Information Management Office
Subject: Express Mail
To: All Laboratory Employees

1. Townsend AFB continues to be the highest user of express mail in all of the Unorthodox Aviation Command. FY'88 costs increased 18% above FY'87 costs and the first two months of FY'89 show 30% increase. Express mail is the most expensive service offered by the U.S. Postal Service (USPS) and the United Parcel Service (UPS) -- a service the Command spent in excess of $172,000.00 on last year.

2. Express mail expenditures can be reduced considerably by simply managing suspenses. We have found many instances where express mail was used for convenience rather than actual need. It should never be used merely because something is addressed to higher headquarters or simply to meet an administrative suspense -- rather an extension to the suspense should be requested. With proper planning and scheduling, the transit time given first class or priority mail will satisfy almost all administrative suspenses.

3. The recent Inspector General (IG) report identified numerous discrepancies and inadequacies with the letters of justification received from our express mail users. To improve in this area and to implement the recommendation of the IG, all future requests for express mail must be accompanied by a letter of justification containing all of the data per the attached sample letter. It is not our intention to refuse express mail service, however we must insure the added cost is in the best interest of the United States Air Force.

Tyrone Newblood
Superintendent, Information Management

1 Atch
Sample Ltr

Hatt shook his head. A perfect example of the difference between traditional bureaucracy and TQM, he thought. Still, it had some good features. Paragraph 1 shows someone has been analyzing costs and found a problem. Even though they probably had not used a control chart, they have clear evidence of a process out of control.

Paragraph 2, he concluded, was also good. When a process is out of control, management's job is to work with the operators to stabilize it. Given a spirit of teamwork, the suggestions given might just be enough to solve the problem.

A good start, he thought, until Paragraph 3 ruined it all. In typical bureaucratic fashion, a "control" is established on the use of express mail by requiring a letter of justification. If time is so critical that express mail must be used, why add a delay for preparing a letter of justification? Instead of adding value to the process, it's just plain counterproductive.

Worst than that, it gives the impression that the purpose of the office is producing letters to suit the IG. Better it should produce rapid mail service to those who need it in an overall economical mail process. If everyone implemented the advice in Paragraph 2, the process would be in control. Then, improvements could be made, such as using fax and computer mail. That would be the TQM approach.

The letter of justification, he mused, really only gave an illusion of control. It would be simple for anyone to file a standard acceptable letter of justification and attach it to every message. It should be done away with. Training the working troops should reduce the express mail load, and a control chart could verify to management and IG inspectors that it was working. Perhaps the letter of justification was mandated by higher authority. In that case, the laboratory Commander should raise the issue to get it out of the system.

Hatt picked up the phone and dialed Newblood's extension.

2 PROCESS FLOW CHARTING

Under Hatt's tactful and friendly approach, Newblood's initial hostility faded, and he agreed with Hatt's conclusions. Further, his professional instincts recognized that the TQM approach that Hatt cited might be a valuable tool that would serve him well in the future. Until his meeting with Hatt, he had dismissed it as just another buzzword.

"All right, Hatt," he said, "you know my problem. I have to provide express mail service and keep the costs down. Let's say I'm just setting up shop. How would I get started if I wanted to use a TQM approach?"

"Well," replied Hatt, "the first step is to understand your process. You could start with a *process flow chart.*"

"What does that look like?"

Hatt went to his blackboard and sketched a diagram. (See Figure 2-1)

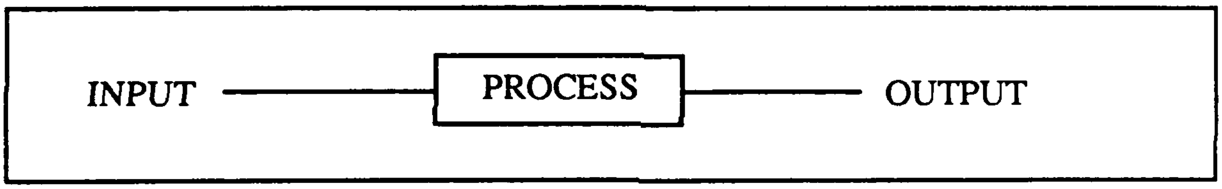

Figure 2-1: Process Flow Chart

"Every process has an input and an output," he explained. "Put another way, each action agency is a customer for some product and has a customer for its products. In your case, you get units of mail from the laboratory offices and supply them to a shipper."

"There's something wrong with that," Newblood responded. "That makes the shipper my customer. Since I pay him, I would think I'm his customer."

"Good point," agreed Hatt. "Since these charts are usually related to manufacturing processes, the output receiver is traditionally called a customer. But to avoid ambiguity, lets call it something else."

"How about receiver?", asked Newblood.

"Fine. So we have a supplier and receiver. We also need to show feedback."

"If you have any. In my process, I don't."

"Disagree!" said Hatt. "Your memo is a feedback to your suppliers, and I presume you have some rules your shipper gives you. Things like package size and weight limits. How about problem calls and bills? That's all feedback."

Newblood nodded. "Okay," he said, "I'll buy that. What else?"

"That's enough for now. How about drawing one for your process?"

Newblood took the chalk, and began drawing. (See Figure 2-2)

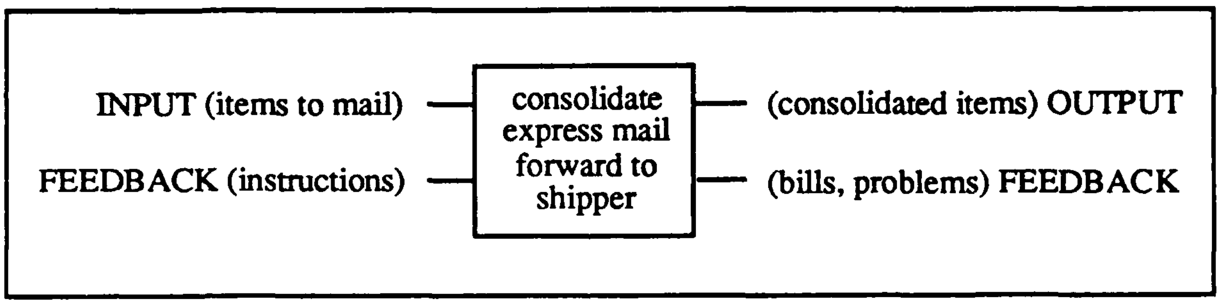

Figure 2-2

Newblood looked thoughtfully at his creation. "Doesn't look like much," he said.

"It will do for a start," responded Hatt. "We'll get into decomposition later. For now, let's accept this as the top level flow chart of what you should be doing. According to your memo, you are actually doing two processes. Here's the other." (See Figure 2-3)

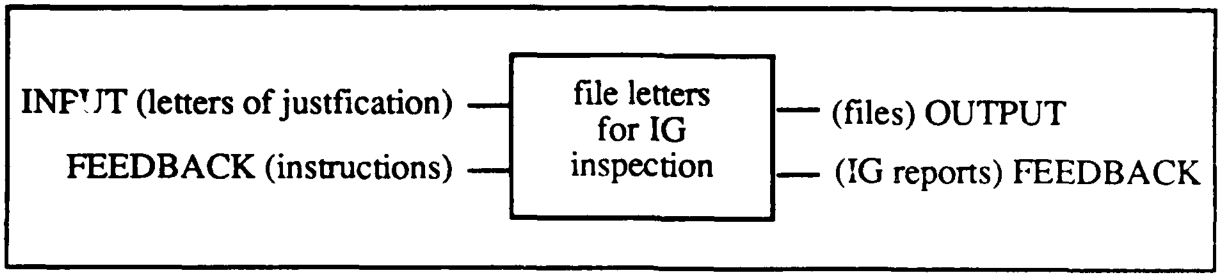

Figure 2-3

Newblood smiled. "Not very productive, is it?"

"No," agreed Hatt. "And all too common. Peter Drucker had it right. He said managers spend too much time worrying about doing things right when they should worry about doing the right things."

"Now," he continued, "let's expand your chart. You can make your box into a series of sub-processes, and add some decision points. Before we do, however, let's be sure you have only one process. What do you do with the bills? Are they just information, or do you have to operate on them?"

"I see what you mean. The bills are information that I use to compute costs, and, as my memo shows, impact the feedback I give my supplier. But I also have to arrange payment. And that process looks like this." (See Figure 2-4)

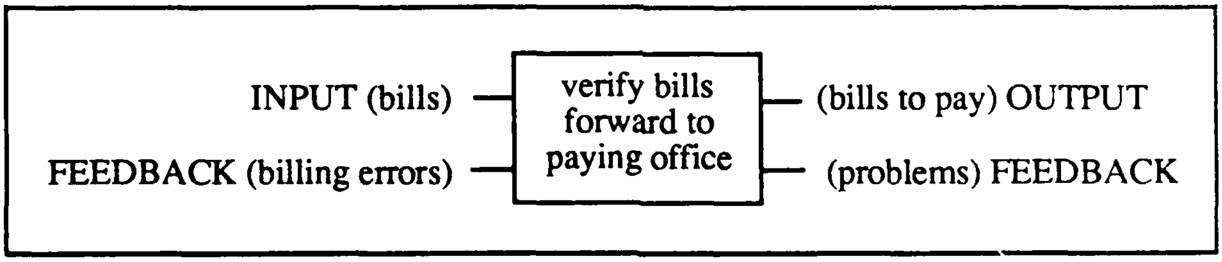

Figure 2-4

Hatt nodded his approval. "Okay," he said, "you have identified another process. Let's use this to show a decomposition. I'll leave out the feedback lines to keep it simple, but don't forget they are there and are your means of communication. I would guess your process looks like this." (See Figure 2-5)

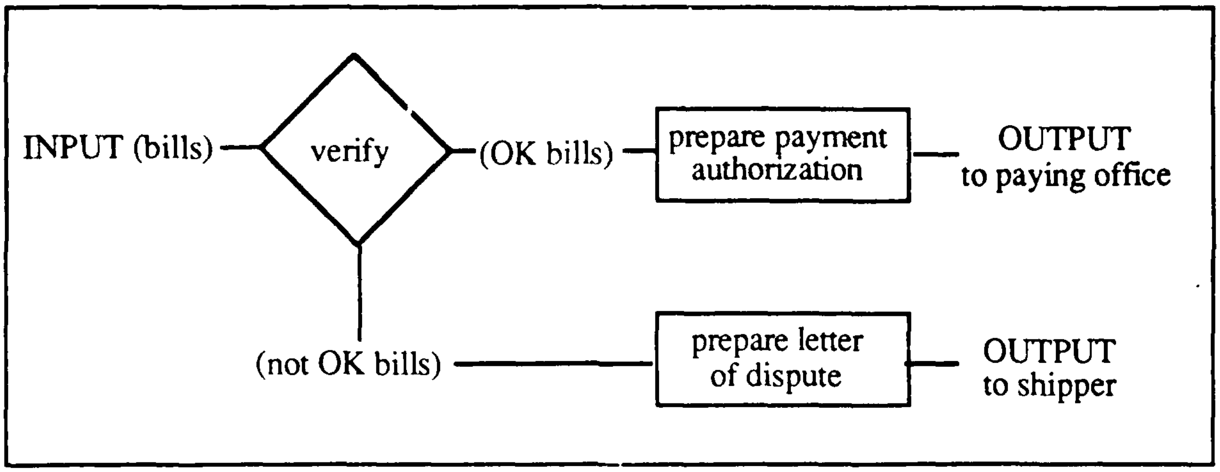

Figure 2-5

"That's about right," responded Newblood, "but so what? The same person does all these things; why do I have tc separate them?"

"In this case, perhaps you don't. Maybe you do, if you want to examine the pay process and dispute process separately. Remember, you use the flow chart as an aid to you, not as a square filling exercise. You describe your process to the level of detail that makes sense to you. You can borrow some symbols from the computer programmers and use diamonds for decision points and special symbols for documentation, or just use boxes for everything. Whatever works for you. The important thing is to be sure the entire process is described. You want to understand it so you can improve it. With the little we've done today, you recognize that you have a process that just provides files for the IG, and two other processes. I am sure you do other things besides handle express mail. Add those to what we did here and you'll have a description of your entire operation."

"Fine," said Newblood, "I'll do that. But once I eliminate the deadwood, I have a bunch of processes that I must do. This chart doesn't tell me anything about how I should be doing them."

"Quite true," replied Hatt. "And, as a matter of fact, that is your responsibility. You are in the best position to decide how the process should be done. The flow charts will identify what processes you work on, but not how to do them, improve them, or even if you need them. You decide these, and you have to base your decisions on the needs of your objectives, the purposes behind the processes."

"Can't help me there, can you?" smirked Newblood.

"Didn't say that," replied Hatt. "Go do your process flow diagram and come back next week. Then, I'll introduce you to the *fishbone.*"

Newblood's process flow chart is shown in the Appendix to Chapter 2.

2 APPENDIX

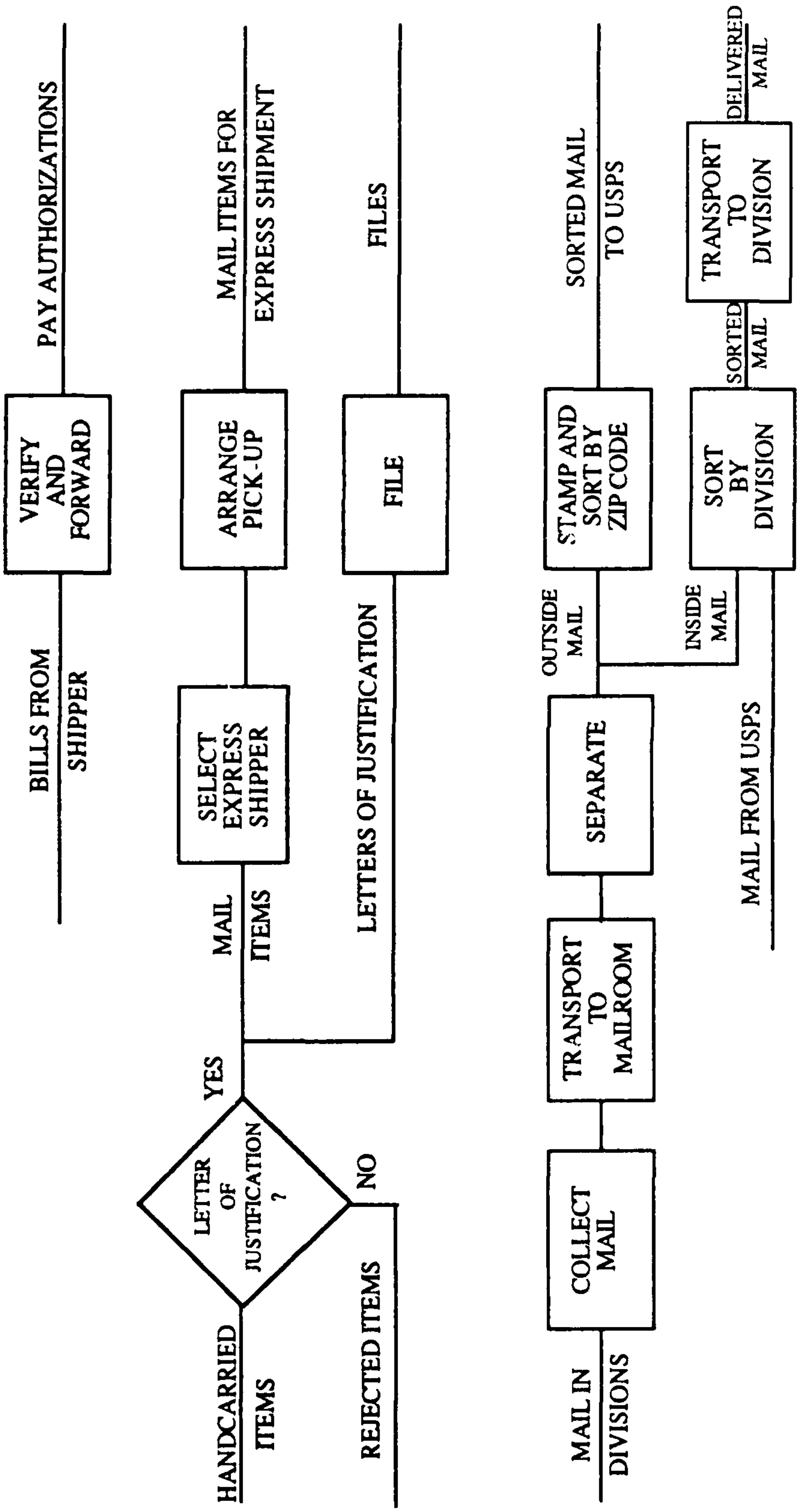

Figure 2-6: Newblood's Process Flow Chart (Feedback Not Shown)

3 ISHIKAWA CHARTS

"So where's this magic fishbone that is going to tell me what to do with my processes?"

"Not quite right," Hatt laughed. "It's not magic and it's a *Fishbone Chart.* More formally, an *Ishikawa Chart* or *cause and effect diagram.* It's called the fishbone chart because that's how it looks. I'll draw it for you." (See Figure 3-1)

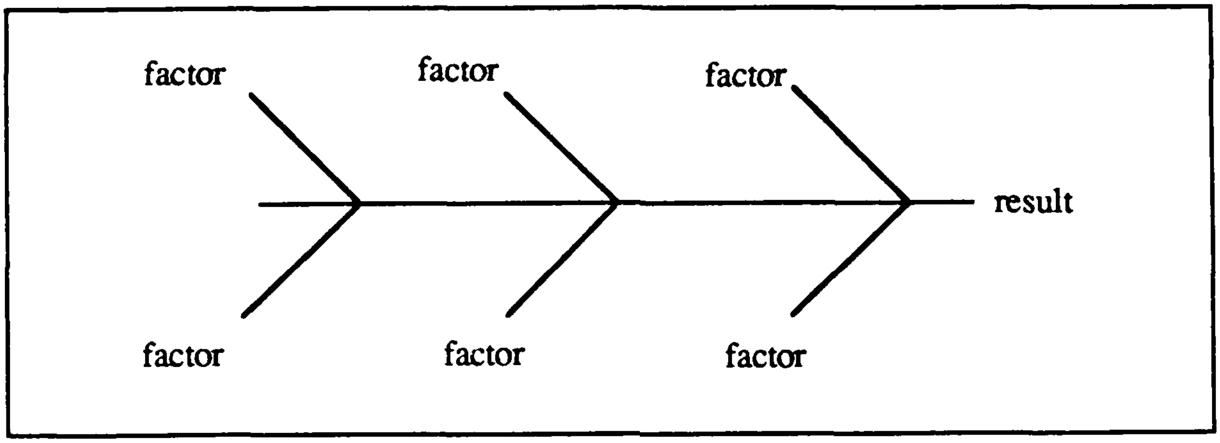

Figure 3-1: Ishikawa Chart

"I see how it got named," commented Newblood, "but I don't see what it does for me. Kindly explain."

"It's purpose is to organize your thinking about what it takes to achieve a goal. The factors are causes and the result is the goal you want to achieve. You could also make the result a problem you want to solve, and the factors would then identify contributors to the problem. But let's proceed looking at a goal. What are you trying to accomplish with the processes you put on your flow chart?"

After a moment of thought, Newblood decided his goal was efficient and economical mail service.

Hatt erased the word "results" and chalked in Newblood's goal. "So how do we get there?" he asked.

"Well, I guess we get everybody to try harder."

"I think you would be better off getting everybody to try smarter," said Hatt. "But you've identified the first factor, which is....."
Hatt wrote, in large letters, "people."

"Okay," replied Newblood, "but people don't work in a vacuum. So I guess the next factor is management."

"I think that's a little too broad. The people factor includes the managers, but there is more to management than that. Can you break it down?"

"How about organization?"

After a few minutes, five factors had been agreed to. (See Figure 3-2)

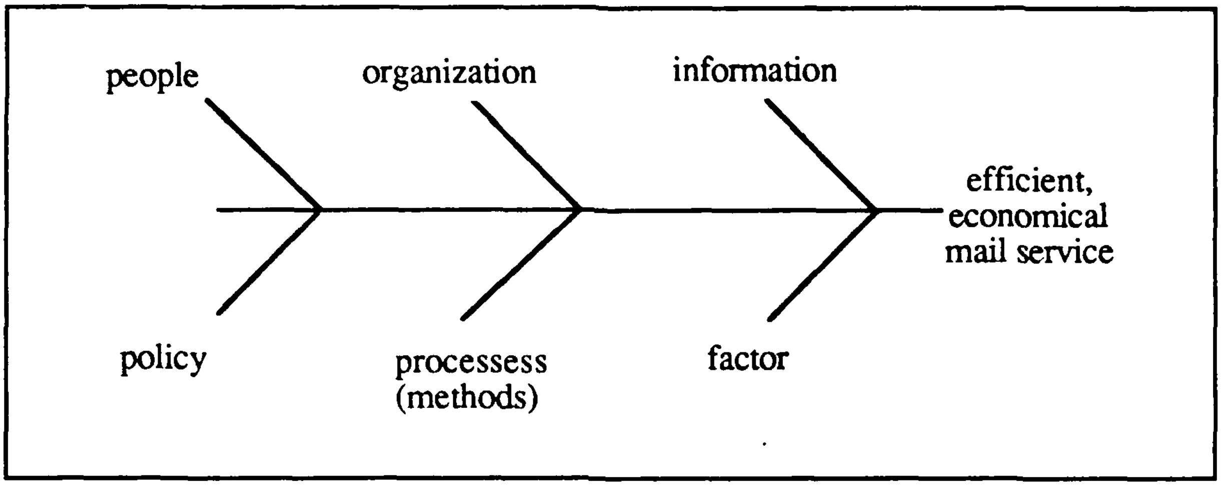

Figure 3-2

"There's no reason we have to have six factors, is there?" asked Newblood.

"Of course not," replied Hatt, "Use as many as makes sense to you. It's your aid."

"So when does it start aiding?"

"Don't be a smart-alec," grinned Hatt. "It's already got you to think about what it takes to reach your goal. Now let's go further by expanding the bones, starting with people."

"The first set of people," he continued, "let's call the workers. These are the people that actually handle the mail, from the originators to the person who gives it to the post office. What do you expect of them?"

"To do the best they can, I guess."

"What defines that?"

Newblood paused for reflection, then replied, "If the originators followed the advice I put in my memos and kept the mail pick up times in mind, I think they would be doing their best. The mail room people have routines to follow, like sorting by zip code. So I guess everyone is doing their best if they follow

instructions. But I don't like that answer, because we expect people to use their ingenuity when problems arise. And the guy that prepares the instructions, that's me, doesn't know everything."

"So what should a worker do when his guidelines don't promote an effective and economical mail service? Just ignore them?"

"No, that would create chaos. I think what he should do is let the management know, so they can change the system."

"Sounds good to me," agreed Hatt. "So our worker's contributions are to follow their guidelines and to identify barriers to achieving the goal. Let's write that down."

Hatt drew a long diagonal line on the blackboard, wrote the word "people" at the top, then added a horizontal line extending from the diagonal. He labelled the line "workers" and under it wrote on separate lines "apply guidelines" and "identify barriers."

"I think I know what the next line is," remarked Newblood. "Someone has to provide the guidelines and listen to the workers. And that's management."

"That's right," answered Hatt. "They also provide the training." Let's add that.

"Looks like we have everybody in those two lines," said Newblood.

"Yes, but let's single out two people for special attention. Who sets the tone for quality throughout the agency?"

"Probably the Commander."

"No probably about it. If the boss doesn't care, no one else will."

"Sold. Who's the other special person."

"That, my friend, is you. Since you are the man in charge of the mail process, we'll give you a place of honor on the fishbone." (See Figure 3-3)

Newblood studied the chart in silence for a few minutes. "Looks like the whole laboratory gets involved with my problems," he said finally.

"Not quite," said Hatt, "but it is true that quality has to be everybody's business. Is there anybody on this chart whom you could eliminate and still describe the people part of a process producing your goal?"

"No, though I probably could narrow down the categories of worker and manager. I might want to use more than one line for workers, since the mail room workers and the mail initiators are different. But still, you have a fairly general

chart there. You could probably use it for any process in the lab, just by changing the title on the last area."

"Probably. When you get into methods, though, you should be fairly unique."

"I presume that's left to the student for a homework exercise."

"Naturally. But let's talk about the policy bone. What policies lead to efficient and economical mail service?"

After some thought, Newblood said, "Don't hold up anything unnecessarily, and don't spend any more money than you have to."

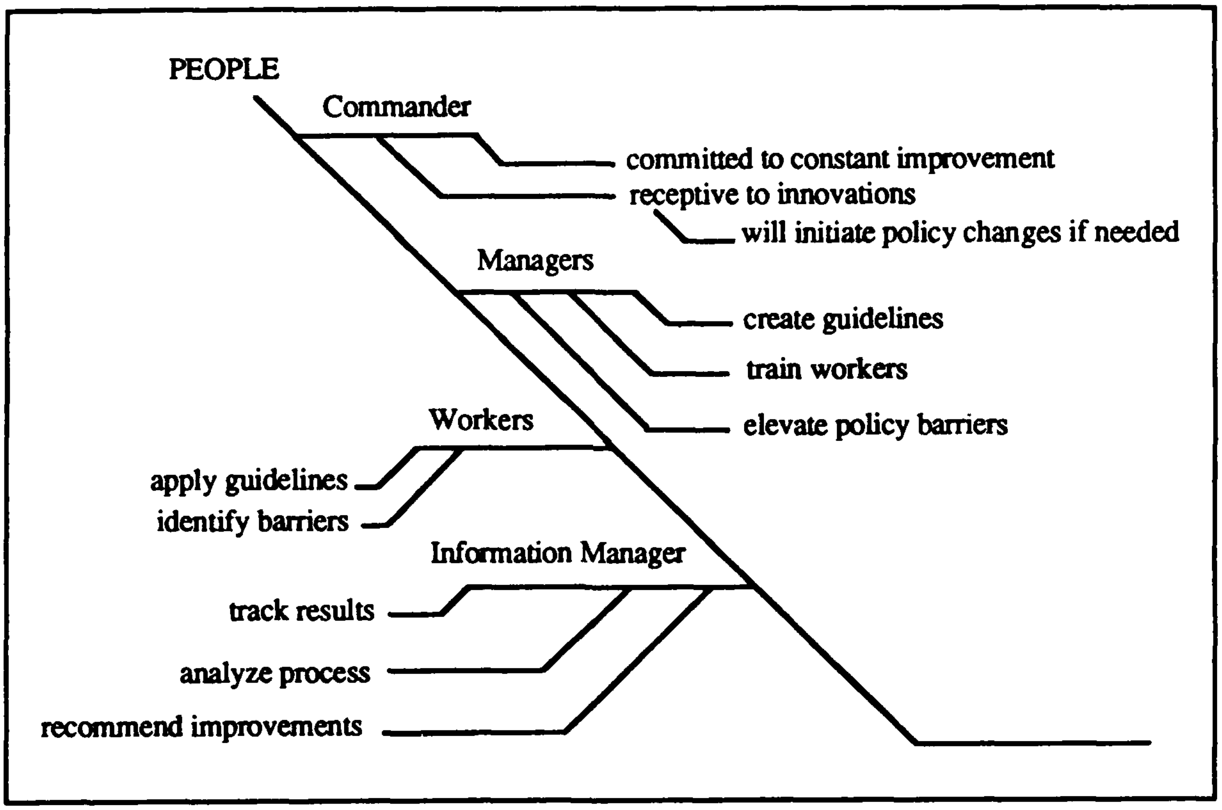

Figure 3-3: People Factor Expansion

"Okay," responded Hatt, "Anything else?"

"I can't think of anything else. But I'll bet you can."

"Just two. First, since the workers have to be trained, adequate training should be a policy, and a TQM-oriented agency should always have a policy of constant improvement. This means eliminating barriers including those imposed on us by regulation. So your policy bone might look like this." (See Figure 3-4)

"Remember that memo you wrote on express mail?" Hatt asked. "How does it stack up against this policy bone?"

"Well," said Newblood, "it was concerned with unnecessary expenses and did some training. But the letter of justification was counterproductive to rapid response. It didn't do anything about improvement, the way you mean it, since it didn't change the system."

"Right," said Hatt. "If you had cancelled the requirement for a letter of justification, that would have been a barrier removal."

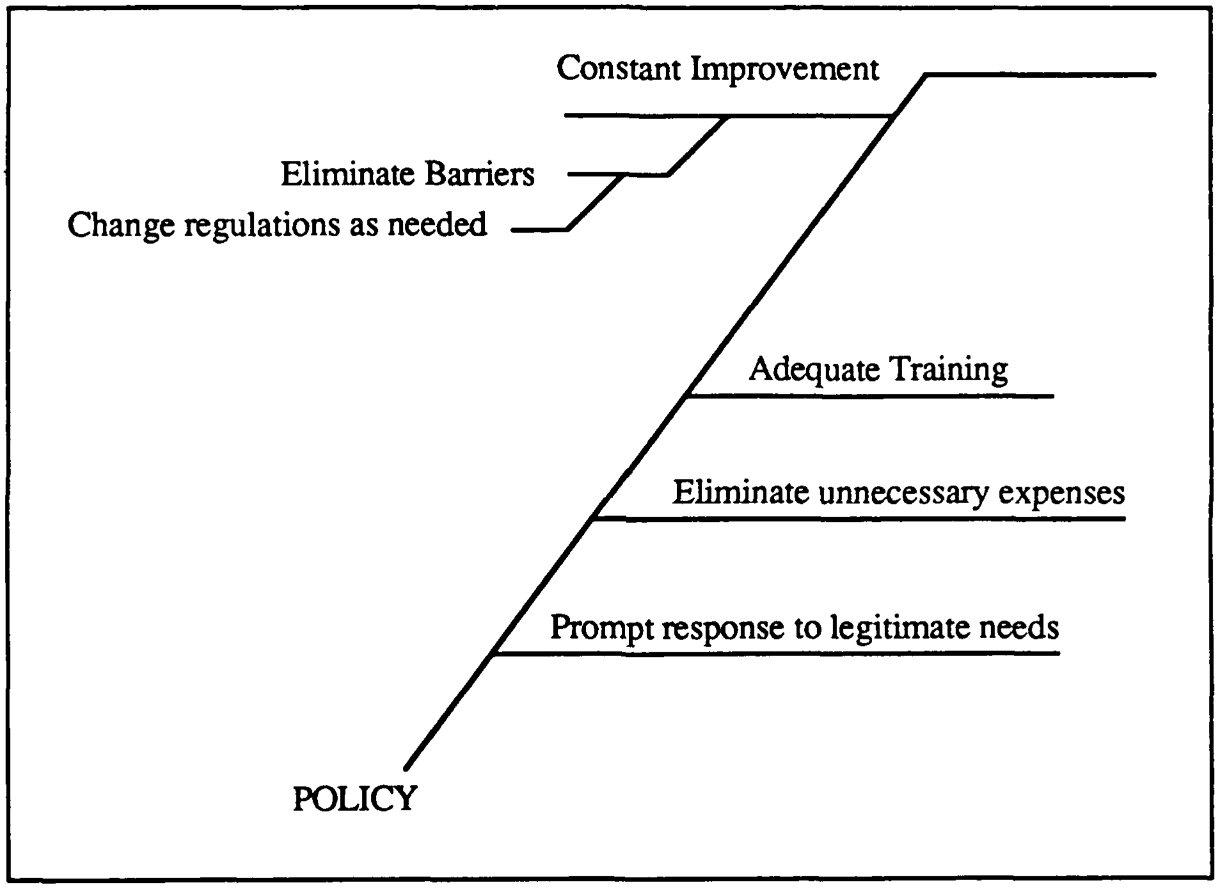

Figure 3-4: Policy Factor Expansion

"That still bothers me," Newblood replied. "If I don't have letters of justification, how do I show the IG that I'm keeping the expenses down? More importantly, how do I know myself? I agree the letters are not the way to go. But what is?"

"One thing at a time. Finish your fishbone. Then I'll tell you about *Control Charts*."

4 STATISTICAL PROCESS CONTROL

The next meeting between Hatt and Newblood was in the latter's office. Hatt noted that Newblood's process flow chart was posted on one wall and an Ishikawa chart on another. He nodded his approval.

"I've got two walls left," said Newblood. "One is for the control chart you mentioned last time. The other is for your scalp if all this TQM stuff doesn't work out."

"If it doesn't, the Commander will beat you to it," replied Hatt. "Are you ready to be enlightened?."

Hatt took the offered chair and opened his briefcase. He began with the question: "What do you know about statistics?"

"Easy, Hatt, I'm just a mailman."

"No excuses, Tyrone. As a manager who cares about quality, you need a small dose of statistics. Just enough to be able to apply *Statistical Quality Control.*"

"I knew there'd be a catch to this TQM business. But go ahead."

"Let's start with a little exercise."

Hatt handed Newblood a sheet of paper on which he had written a column of numbers. "What's the average of these figures?" (See Figure 4-1)

10
10
10
10
10
50
60
80
80
140
200

Figure 4-1

"I smell a trick," commented Newblood. Nevertheless, he began punching the numbers into a calculator on his desk. "I get 60," he announced, "now what's the catch?"

"The catch is that 60 isn't <u>the</u> average, but <u>an</u> average. To be precise, it's the ***mean***. You got it by adding the figures and dividing by the number of entries. Nothing wrong with that, and we'll be dealing with the mean, but you should be aware of other ways to compute an average."

"Such as?"

"Well, let's say the figures represents the salaries of a small plant, in thousands of dollars. Five people make $10,000 a year, one makes $200,000, and the rest are somewhere in-between. The union claims the workers are underpaid, and the

management claims they are not. Management says the average salary is $60,000. The union says it's $10,000. Who's right?"

"Since management computed their average the same way I did, I have to conclude they are right. But more people make $10,000 than any other salary. If that's a legitimate definition of average, the union is right, too. It seems to depend on what you call an average."

"Exactly. And that's why we need more precise terms. Management is using the mean, and the union is using what we call the *mode*. It is a legitimate measure of average and makes more sense than the mean in some cases. Another 'average' is the *median*, which is the value that divides our data into two equal parts. In this case, five people make less than $50,000 and five make more, so the median salary is $50,000."

"Okay, I see the difference. Now what?"

"Now we get into dispersion. The average, as my example shows, doesn't tell the whole story. Even when the mean, the mode, and the median are identical, there is still something else to consider. Here's another contrived example." (See Figure 4-2)

Measured Value (Inches)	Producer A	Producer B
104	-	5
103	-	10
102	10	20
101	50	35
100	100	70
99	50	35
98	10	20
97	-	10
96	-	5

Figure 4-2

"Let's say the measured value is the length of a rod made by two different manufacturers," explained Hatt, "and the other numbers are the number of rods produced to that measurement in one lot. If you added them up, you would find each manufacturer made 210 rods and the average length, whether mean, mode or median, is 100 inches for rods produced by either. But are the two suppliers providing equivalent products?"

"Depends on how much the spread bothers you, I would think," Newblood responded. "If I wanted rods 100 inches long and could live with plus or minus four inches in length, I don't think I would care. If I had only a two inch tolerance,

I'd be scrapping 30 rods from manufacturer B every lot. And if I needed 100 inches exactly, I wouldn't be too happy with either."

Hatt waved his hand. "There's a lot we have to talk about in what you just said. Let's take those comments one at a time, in reverse order. First of all, you never get a product exactly meeting any measurement. There is always a spread. Maybe it's measured in thousands of an inch, but there is always some dispersion. If you ordered the rods without specifying a tolerance, you'd probably wind up in an argument on how close is good enough."

"Dispersion can be described by various means. The most common is some sort of distribution chart. Suppose we took the data for supplier B and plotted it in a bar chart. The length of the bars represents the number of pieces meeting a particular measurement. I should note that the values in the chart are to the nearest inch, so a measurement of 101, for example, includes every measurement from 100.500 to 101.499 to the limits of measurement accuracy. This kind of bar chart is called a *histogram*, and the histogram for Supplier B looks like this."

Hatt took a blank sheet of paper and began drawing (see Figure 4-3).

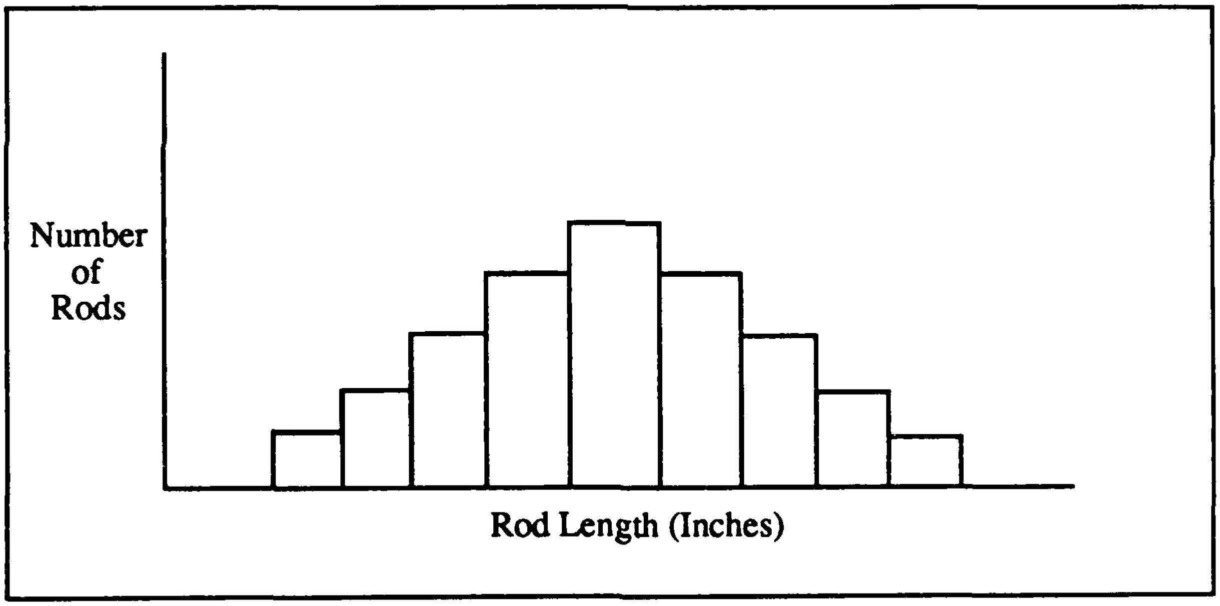

Figure 4-3

"Now," Hatt continued, "if we drew a smooth curve connecting the mid points of each bar we would get something like this." (See Figure 4-4)

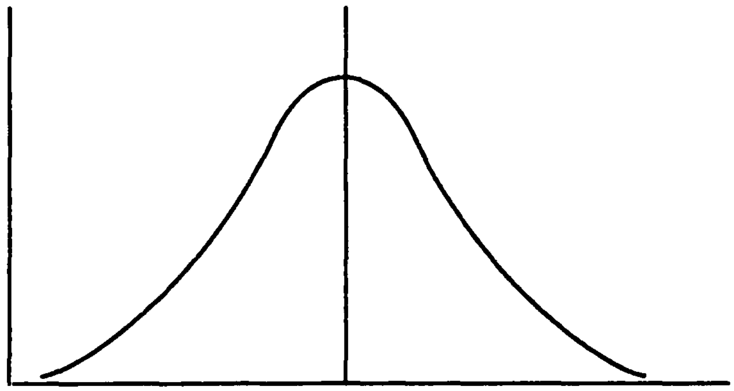

Figure 4-4

"This particular curve looks like what we call the *Normal Distribution*, which is a bell shaped curve symmetrical about the mean value, quite common in practical situations, and the basis for some of the stuff I'll cover later. If the area under the curve is set equal to one, the area between any two points on the horizontal scale represents the probability that a randomly selected bar will measure between the values represented by the points. In this case the area between 98 and 101 would be the probability that a bar is at least 98 inches long but no more than 101 inches long. This type of curve is called a *Probability Density Function*. It can have any closed shape, so long as the area is equal to one, but certain curves are more useful than others. The normal curve is quite useful."

"So much for probability distributions," he continued, "and back to your comments. Your case where a two-inch spread was acceptable leads right into the differences between process control and process capability. If monthly samples from supplier B followed a predictable normal distribution, his process is in control. It's in control, but not capable of producing rods always within our two unit length tolerance. What's important about this difference is that when the process is in control, the workers are doing their best. If that's not good enough, it's management's job to improve the process. The workers work in the process, the manager's work on the process. Supplier B won't get any better product by motivating his workers; he must change his process."

"Finally, I have to disagree with your statement that when you can live with a spread of plus or minus four inches, you are indifferent to the supplier. We've assumed that the mean of the lot was our desired value. But not only will rods in a lot vary, but lots will vary. Two lots from the same supplier will have different means. Any change in the mean of the products from Supplier B and you're buying a lot of scrap. Reasonable variation in A's product won't hurt. Also, suppose instead of rod length, we were talking about the diameter of a piston. Maybe a four unit change from nominal would still work, but some pistons would

be too tight and some too loose to provide the intended performance of whatever they were installed in. The more variable the parts are, the more likely it is that an assembly of parts will be out of tolerance. There may be times when it truly doesn't matter, like when buying fence posts, perhaps, but in general supplier A should be much preferred to supplier B."

Newblood nodded. "I am humbled by your erudition," he said, "and will buy the whole package. But what happened to the chart you were going to tell me about?"

"Patience, my friend. You need to understand these concepts to understand the use of a *control chart*. But, we are far enough along to see what it looks like."

5 CONTROL CHARTS

Hatt reached into his briefcase and produced another piece of paper. (See Figure 5-1)

```
UCL--------------------------------------------------------------------------------
Mean-------------------------------------------------------------------------------
LCL--------------------------------------------------------------------------------
```

Figure 5-1: Control Chart

"This is the skeleton for a *Control Chart.*." Hatt explained. "The middle line is the expected mean of the process output. UCL means upper control limit and LCL, lower control limit. These define the expected variation of the mean. For example, if you plotted the number of express mail requests each month, and the process was in control, you would expect each month's number to vary randomly around the mean and within the control limits."

"Here's an example of a process in control" he continued, handing Newblood another sheet of paper. (See Figure 5-2)

```
UCL-------------------------------------------------------------------------
                     x           x
                         x                      x     x
Mean--------x-------------------------------------------------x------------
                x
                             x       x     x                          x
LCL-------------------------------------------------------------------------
Month       1   2    3   4   5   6   7     8    9     10      11      12
```

Figure 5-2: In-Control Process

"There are two points I want to make with this chart," he said. "First, so long as the points are inside the control limits, you shouldn't fiddle with the process. Suppose, for example, that these points represented mean length of the rods we talked about. If the supplier noted the low value in month five, he might be tempted to adjust his machinery to make longer rods. Then, in month six, the point would be outside the upper control limit. If he made another adjustment then, the rods in

month seven might be too short. All his adjustments would accomplish is to increase the variance of the product. The moral is that when you are in control, don't adjust the process."

"If it ain't broke, don't fix it," interjected Newblood.

"In a sense, yes, but we don't like that expression. The idea behind TQM is constant improvement, so we always want to fix it. The difference is that we want to change the process to make it more capable, not to make counterproductive adjustments to a process in control."

"Understood. What's your second point?"

"My second point is that when the IG calls, a control chart shows him that you are doing your job better than a million letters of justification."

"Touché, Hatt. But does the IG know that?"

"TQM is a DoD wide initiative, so sooner or later everyone will get the word. In the meantime, you can educate the ones looking at your process. You'll be doing us all a favor."

Newblood studied the chart a while, then said, "this assumes I have some number for the mean, and other numbers for the control limits. Where do I get these?"

"You track your process and gather data. For your express mail analysis, you could track costs or number of requests on a monthly basis. First, just plot these for an eyeball test on whether or not you have a stable mean. From your memo, you are having rising expenses, which means your process is not in control. But let's assume everyone took your advice to heart, and the costs stabilized. Then you add up the monthly cost figures and divide by the number of months and you have your process mean. If you were making rods, you could take the mean of each month's production, add these and divide by the number of months. There's an interesting law of statistics called the central limit theorem which states that the mean of the means of your sample will equal the mean of the population, the population being all the rods ever produced under a stable process."

"That's easy enough. How about the upper and lower control limits?"

"The control limits represent the extent to which we expect the process to vary while it's in control. More precisely, it represents the extent to which we expect the mean of a sample from the process to vary. Variation is measured in a couple of ways. The one used here is called the *Standard Deviation*. It's calculated by either of these formulas."

Hatt handed Newblood another piece of paper. (See Figure 5-3)

"Using the first formula, you would take the monthly costs for express mail, square each of them, add, and divide by the number of months. From this, subtract the square of the mean monthly cost. Finally, take the square root of this and you have one standard deviation."

"The second formula works a little differently, but gives the same answer. Using it, you take each month's cost, substract the mean cost, and square the result. Add all the squares together. Then divide by the number of months and take the square root."

$$s = \sqrt{\sum_{i=1}^{n} X_i^{2}/n - \bar{X}^2} \qquad s = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (X_i - \bar{X})^2}$$

X_i = measured value of a particular sample

$\bar{X} = \sum X_i/n$ = mean of measurements

n = number of measurements

Figure 5-3: Standard Deviation

"It's a bit of dog work, but no big deal," said Newblood. "Then what do I do with it?"

"This gives you the standard deviation of the sample you took. There are standard conversion factors, which I'll give you, to convert this to an estimate of the population standard deviation. If your sample is big enough, say 25 or more, its standard deviation will be close to the standard deviation of the population without conversion. Then, the expected standard deviation of the mean of any future sample will be the population standard deviation divided by the square root of the number in the sample."

"By convention, the upper control limit is the expected sample mean plus three times the expected standard deviation of the sample. The lower control limit is the mean minus three times the standard deviation. That's all there is to it."

"I can handle that, but I don't understand it. Why three times the standard deviation?"

"Fair enough. First of all, a Russian mathematician named Chebyshev proved that a minimum of about 89% of all data in any distribution will lie within three

standard deviations of the mean. Eight ninths to be precise. So if we set the control limits at three standard deviations we would expect at least eight out of nine measurements to be inside, and it's reasonable to be concerned about a measurement outside. Actually, with sampling, we have much more reason to assume a figure out of the control limits represents a problem. I mentioned that the central limit theorem stated the mean of sample means will equal the population mean. It also states that the means of samples taken from any distribution will conform to a normal distribution, no matter what the original distribution. For the normal distribution, plus and minus three standard deviations from the mean includes 99.7% of all data. So there are only three chances in a thousand that a point outside the control limits is due to random variation."

"I guess I'm satisfied." responded Newblood. He looked at the pile of Hatt's handouts on his desk. "Too many papers, Hatt," he complained.

"Still one step ahead," Hatt grinned, handing Newblood another sheet. "Here's a summary of today's lesson." (See Appendix to Chapter 5)

"Thanks, Hatt. Now is this all I need?"

"Sorry, no. It's all you need to understand statistical process control, but you'll need a little more to make effective use of it. For example, to compute the standard deviation of the rods in our example, you'd do a lot of dog work, if there wasn't a shorter way than I've shown you. Also, if you were producing rods, you be concerned about the spread of length in each lot. The mean might remain the same and the control chart wouldn't warn you that the spread was increasing. For that you need a range chart. Also, we've been dealing with measured values. You might want to control proportions, like percent defective, or rates, like failure rate. These take some modification to the procedure."

Newblood shook his head. "I guess I'm stuck with you for a while. Same time next week, your place?"

5 APPENDIX: CONTROL CHARTS

UCL--
Mean--
LCL--

X_i = Measured value of one unit
n = No. of units in one sample

$$s = \sqrt{\sum_{i=1}^{n} X_i^2/n - \bar{X}^2} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})^2}$$

s = Standard deviation of sample
s' = Estimated standard deviation of population = s/c
(c from following table)

Mean = $\bar{X}$

Upper control limit (UCL) = $\bar{X} + 3(s'/\sqrt{n})$

Lower control limit (LCL) = $\bar{X} - 3(s'/\sqrt{n})$

Converting sample standard deviation to an estimate of the population standard deviation.

n = Number of observations in sample
c = Conversion factor
s' = Population standard deviation = s/c
s = Sample standard deviation

n	c
2	0.5642
3	0.7236
4	0.7979
5	0.8407
6	0.8686
7	0.8882
8	0.9027
9	0.9139
10	0.9227
11	0.9300
12	0.9359
13	0.9410
14	0.9453
15	0.9490
16	0.9523
17	0.9551
18	0.9576
19	0.9599
20	0.9619
21	0.9633
22	0.9655
23	0.9670
24	0.9684
25	0.9696
30	0.9748
35	0.9784
40	0.9811
45	0.9832
50	0.9849
55	0.9863
60	0.9874
65	0.9884
70	0.9892
75	0.9900
80	0.9906
85	0.9912
90	0.9916
95	0.9921
100	0.9925

Assumes sampling from a normal universe.

6 RANGE CHARTS

"You were right, Hatt. Computing the standard deviation of the rods would be a pain. If I had a sample of ten each month and used ten months that's 100 figures I have to square and add."

"Hello to you, too, Tyrone," replied Hatt. "Glad to see you've been doing your homework."

"Oh, yeah, hello. Anyway, I could have my PC do it, but you said you had an easier way."

"Right. Let's introduce a new concept, which we'll call the *range*."

"Must we?"

"Come on, Tyrone, it really hasn't been that tough, has it?"

"Well, no," admitted Newblood, "but I don't want to encourage you. I'm not about to become a statistician."

"I'm not one either," replied Hatt, "but we use the tools that serve us. And to use statistical process control, you need to know something about statistics."

"Okay, but be gentle. What's this range?"

"The range is simply the difference between the highest and lowest value of your sample. If you took ten rods and found that the longest was 104 units and the shortest was 96, the difference between these is 8 units. That's the range."

"Got it. Then what?"

"The statisticians have worked out a relation between the range and the standard deviation of the population. You multiply the range by a factor depending on the sample size. I'll give you a table. As an example, the factor for a sample size of 10 is .32. So if your range was 8, your standard deviation is estimated at 8 times .32 which is ..." Hatt pulled a calculator out of his pocket and entered the data... "2.56."

"That's easy, but I'd be a little uneasy basing my chart on one range measurement. Wouldn't the range vary month to month?"

"Right. So the better procedure would be to take a series of ranges, and use the mean of the series with the factor to compute the estimated standard deviation. For a bonus, you use the mean as the mean of your *range control chart*."

"I already have a control chart. Why do I need a range control chart?"

"We'll get to that shortly. In the meantime, let's make your life easier yet. What do you do with the standard deviation?"

"I use it to get my control limits. I multiply by three because I want to use three standard deviations, and divide by the square root of the number in my sample because the deviation of my sample mean is different from the population deviation by that factor."

"Right. I've taught you well, haven't I?" smiled Hatt. "But there's no need to do that multiplying or dividing. It's all been combined with the conversion factor in tables, so your control limits can be computed directly from the range. You just multiply the average range by a factor dependent on your sample size, add the result to the mean for the upper control limit and subtract it for the lower control limit. The statisticians have also worked out a factor to determine the upper and lower control limits for the range. In this case, you have two factors, one for the upper control limit and one for the lower."

"Returning to your question," he continued, "you need a range chart when you are concerned with the variation within a lot. For your monthly cost of express mail, it's non relevant, but for the rod example, it is. You want the mean length of rods to be in control and you want the variation in length to be in control also."

"Okay, you win again," Newblood responded. "I presume you'll give me these tables and your usual summary instructions. Am I through yet?"

"Just a couple of notes. First of all, any time you calculate a lower control limit and get a negative number, just set it to zero. A negative value has no meaning."

"Secondly, you might run into another way of estimating the population standard deviation, different from the way I taught you using the table." Hatt began writing. (See Figure 6-1)

$$s' = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}}$$

Figure 6-1: Standard Deviation

"This is just the formula for sample standard deviation, with n-1 replacing n. It's generally used with small sample sizes, as an alternate to the conversion table."

"I'll keep it on file. Now do I know everything I need to make control charts?"

"Only if you are concerned solely with the control of variables. If you want to control proportions, such as the percent defects in a lot of materials, or in your case, the percent of total mail that need expressing, you need some more instruction. Also, rates, like the failure rates of your machines, are handled a little differently. Here's the handout for this lesson. Same time next week?"

"Agreed." Newblood scanned through Hatt's handout as he left. (See Appendix to Chapter 6)

6 APPENDIX: RANGE CHARTS

UCL---
Mean--
LCL---

$\bar{R}$ = Average range = $\sum_{i=1}^{j} R_i/j$

$\bar{R}_i$ = Range in sample i = highest value - lowest value

j = Number of samples

For $\bar{X}$ (variable) chart

Mean = $\bar{X}$

UCL = $\bar{X} + A_2\bar{R}$

LCL = $\bar{X} - A_2\bar{R}$

For R (range) chart

Mean = $\bar{R}$

UCL = $d_4\bar{X}$

LCL = $d_3\bar{R}$

n = Number of observations in one sample

A_2, d_3, d_4 from the following Table.

n	A_2	d_3	d_4
2	1.88	0	3.27
3	1.02	0	2.57
4	0.73	0	2.28
5	0.58	0	2.11
6	0.48	0	2.00
7	0.42	0.08	1.92
8	0.37	0.14	1.86
9	0.34	0.18	1.82
10	0.31	0.22	1.78
11	0.29	0.26	1.74
12	0.27	0.28	1.72
13	0.25	0.31	1.69
14	0.24	0.33	1.67
15	0.22	0.35	1.65
16	0.21	0.36	1.64
17	0.20	0.38	1.62
18	0.19	0.39	1.61
19	0.19	0.40	1.60
20	0.18	0.41	1.59

Factors assume normal population.

Estimating population standard deviation (s') from range data.

n = Number of observations in one sample

n	d_2
2	1.128
3	1.693
4	2.059
5	2.326
6	2.534
7	2.704
8	2.847
9	2.970
10	3.078
11	3.173
12	3.258
13	3.336
14	3.407
15	3.472
16	3.532
17	3.588
18	3.640
19	3.689
20	3.735
21	3.778
22	3.819
23	3.858
24	3.895
25	3.931
30	4.086
35	4.213
40	4.322
45	4.415
50	4.498
55	4.572
60	4.639
65	4.699
70	4.755
75	4.806
80	4.854
85	4.898
90	4.939
100	5.015

$$s' = \frac{\bar{R}}{d_2}$$

7 CONTROLLING PROPORTIONS & RATES

"Hello, Hatt. Here I am to be enlightened again."

"Welcome, Tyrone, and you can call me Ari if you like. Most people do."

"Hatt's easier. I've been practicing making control charts, and it's really pretty easy. But you mentioned that I might want to consider my express mailings as a percent of total mailings, and that makes sense to me. So how do I do it?"

"It's really the same method, but you calculate the standard deviation by a different formula," Hatt replied. "Let's start with a new term which is the fraction of all mail that is expressed. In our rod example it could be fraction of rods produced which are defective. Or the fraction of balls in an urn which are red. Anything that you can describe with a yes or no. Either it's express mail or it isn't. Clear so far?"

Newblood nodded. "Okay," he said, "Continue."

Hatt crossed to the blackboard as he continued, "we use the symbol $\bar{p}$ for this. The standard deviation of a lot is given by this formula." (See Figure 7-1)

$$s = \sqrt{\frac{\bar{p}\,(1-\bar{p})}{n}}$$

Figure 7-1

"Since $\bar{p}$ defines the mean of the process, it establishes the center line of the control chart, and the control limits are." (see Figure 7-2)

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}\,(1-\bar{p})}{n}}$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}\,(1-\bar{p})}{n}}$$

Figure 7-2

"Okay," said Newblood, "so all I have to do is find $\bar{p}$. I presume I do that by taking some data and dividing the number of pieces of express mail by the total mail handled."

"Right. Only there's one thing to be careful of. Since you are estimating the ratio for the process, you need a large sample. Also, if you gather data on a monthly basis, use the total number of express mail and overall mail for the period. Don't compute $\bar{p}$ for each month and average the values."

"Why not?"

"Because you can't average averages unless each is based on the same sample size. For example, if you had a month with one piece of mail and it was expressed, and another month with 100 pieces of which one was expressed, your overall $\bar{p}$ would be two divided by 101 or roughly .02. If you took monthly averages, you would have 1.00 for the first month and .01 for the second, and the average of the two would be .505. So you would be expecting over half your mail to be expressed, which the data does not support. That's an exaggerated example, of course, but it shows what happens."

"Okay, so I use total pieces of express mail divided by total pieces of mail to get the $\bar{p}$ in the formulas. But the points I plot on the control chart are the monthly averages, right?"

"Right. But this brings up another point. Your control limits are based on the number of samples, in this case the total pieces of mail in a month. So the limits will change each month."

"You mean I have to compute my control limits each month?"

"Right. No big deal, though. The only change to our formulas is the sample size, n. So we can rewrite them like this ..." (See Figure 7-3)

$$UCL = \bar{p} + \frac{3\sqrt{\bar{p}\,(1 - \bar{p})}}{\sqrt{n}}$$

$$LCL = \bar{p} - \frac{3\sqrt{\bar{p}\,(1 - \bar{p})}}{\sqrt{n}}$$

Figure 7-3

" ... and once we have established a value of $\bar{p}$ we can compute the value of the numerator as a constant. Then each month we take the square root of the number of mailings and divide it into the constant. Add and subtract this from $\bar{p}$ and we get our monthly control limit."

"Yeah, I see, but I don't like it. We didn't need to do this for the variable control charts. What's the difference?"

"The difference is that we had tacitly assumed constant sample sizes. One measure of the number of express mailings per month, and an assumed constant number of samples for our rod example. You could do the same thing here, by randomly selecting a constant number of mailings per month. That would probably be tricky, and I think you would rather use the total number anyway. If you were making rods and wanted control charts on the number of defects you could select a constant number of samples per lot and keep the control limits constant."

"Okay, I guess. So I use this to track my express mailings as a proportion of total mailings and the control chart for variables to track the monthly number of express mailing by themselves?"

"You can do it like that, but there is a way to combine the two. If you multiply the formulas by n, the number of pieces of mail in a month, you get these formulas." (See Figure 7-4)

$$UCL = n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})} = \bar{X} + 3\sqrt{\bar{X}(1-\bar{p})}$$

$$LCL = n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})} = \bar{X} - 3\sqrt{\bar{X}(1-\bar{p})}$$

$$\bar{X} = n\bar{p}$$

Figure 7-4

"Since n is the number of pieces of mail, and $\bar{p}$ is the proportion expressed, n times $\bar{p}$ is the expected number of express mailings. So you can plot by proportion or number. The difference is really only a scale change, so you could plot both on one graph by having two scales on it, like this." (See Figure 7-5)

$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$	$\bar{X} + 3\sqrt{\bar{X}(1-\bar{p})} = UCL$
$Mean = \bar{p}$	$\bar{X} = n\bar{p} = Mean$
$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$	$\bar{X} - 3\sqrt{\bar{X}(1-\bar{p})} = LCL$

Figure 7-5

"I can handle that, I guess. I presume I have to adjust my charts each month unless my volume of mail holds reasonably constant. Now is that all I need to know about proportion control charts?"

"Yes, but, as usual, I have some other comments. First, if you see any benefit to expressing $\bar{p}$ as a percent rather than a proportion, just multiply the control chart $\bar{p}$ scale by 100. If the expected $\bar{p}$ is .15, your mean line would be 15%."

"Also, $\bar{p}$ is based on some measurements and the world might change, so it's a good idea to recheck the average value of $\bar{p}$ every so often."

"Okay," responded Newblood. "Now you were going to tell me how to make control charts based on rates."

"Rates, I think, are the easiest of all to chart. Let's say you were interested in the failure rate of some machine. You have some data to establish the expected mean. Then the standard deviation is simply the square root of the mean. So the upper control limit is the mean plus three times the square root of the mean. The lower limit is the mean minus three times the square root, or zero if that gives a negative value." (See Figure 7-6)

$$r = \text{Mean Rate}$$

$$UCL = r + 3\sqrt{r}$$

$$LCL = r - 3\sqrt{r} \qquad (\geq 0)$$

Figure 7-6

"This," he continued, "assumes a few things. It's based on a distribution called the Poisson, which is useful in calculating the probability of any given number of events happening when you know the average rate of occurrence. It assumes that every event is independent, that the probability of each occurrence is small, and that a large number of opportunities for the event are available. For example, a failure doesn't make another any more or less likely, the failure rate per hour is low, and a large number of hours are included in the sample. When these assumptions are true, or reasonably close, the Poisson can be used to set the control limits. The formulas I just described do this for the simple case where the rate applies to the total sample and each sample is reasonably identical. For example, the rate may be failures per month for a machine so long as the operation of the machine is about the same from month to month."

"What happens when it isn't?" asked Newblood.

"We get a little more complicated," Hatt replied, "but not much. We make the rate failures per operation or failures per hour, whatever fits, and get the mean from data we have by dividing the total failures by the total hours or operations. To get the control limits, we take the square root of this mean, multiply by three, as before, but then divide this for each sample we take by the square root of the number of hours (or operations) in the sample. This value is added to the average to get the upper limit and subtracted for the lower, but again, the lower limit is not allowed to be less than zero. This of course means that the control limits can vary from month to month, and that the values plotted on the control chart are not the number of failures each month, but the number of failures divided by the number of hours or operations of the machine in that month. Am I clear?" (See Figure 7-7)

$$u = \text{Mean Rate, } n = \text{Units in sample}$$

$$UCL = u + \frac{3\sqrt{u}}{\sqrt{n}}$$

$$LCL = u - \frac{3\sqrt{u}}{\sqrt{n}}$$

Figure 7-7

"I think so," replied Newblood. "I'll have to keep my formulas straight, but I should be able to make control charts on my choice of variables, proportions or rates, depending on what I want to control. But that makes me wonder, how many things do I want to keep track of? How do I keep it down to what's important?"

"For that you need some other techniques. Also, you have to get your process in control before you start charting it. Let's leave these for our next meeting. Same time next week?"

7 APPENDIX: CONTROLLING PROPORTIONS & RATES

UCL--
Mean--
LCL--

Proportions (1)

$$\text{Mean} = \bar{p} = \text{Average Fraction Defective} = \frac{\text{Number Defective}}{\text{Total Units}}$$

$$\text{UCL} = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

$$\text{LCL} = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \quad (\geq 0)$$

Proportions (2)

$$\text{Mean} = \bar{X} = \text{Average Number of Defects in Sample}$$

$$\text{UCL} = \bar{X} + 3\sqrt{\bar{X}(1-\bar{p})}$$

$$\text{LCL} = \bar{X} - 3\sqrt{\bar{X}(1-\bar{p})} \quad (\geq 0)$$

Rates

$$r = \text{Average Number of Failures per Month}$$

$$\text{UCL} = r + 3\sqrt{r}$$

$$\text{LCL} = r - 3\sqrt{r} \quad (\geq 0)$$

$$u = \text{Average Number of Failures per Hour (or Operation)}$$

$$\text{UCL} = u + \frac{3\sqrt{u}}{\sqrt{n}} \qquad \text{LCL} = u - \frac{3\sqrt{u}}{\sqrt{n}} \qquad (\geq 0)$$

$$n = \text{Number of Hours (Operations) in Sample}$$

8 ANALYZING DATA

"Hatt," Newblood complained, "I'm all set to go on control charting, but I still haven't a feel for how I decide what needs charting. Some things are obvious, like my monthly costs, but I think I should be charting the things that contribute to the costs, especially since the costs are still out of control. But I don't want to bog down in charts. I want to find the critical processes, determine which are out of control, and get them in control."

Hatt nodded. "More than that," he said, "even a process in control may not be good enough, and even when everything seems fine you should be looking for ways to improve. So let's talk about some tools that might help."

"What you are doing," he continued, "is essentially detective work. You will be using data as clues and inducing the cause of variations in your process outputs. You start by organizing the data in some fashion that tells you something."

Hatt walked over to the blackboard and began drawing. "Remember this." (See Figure 8-1)

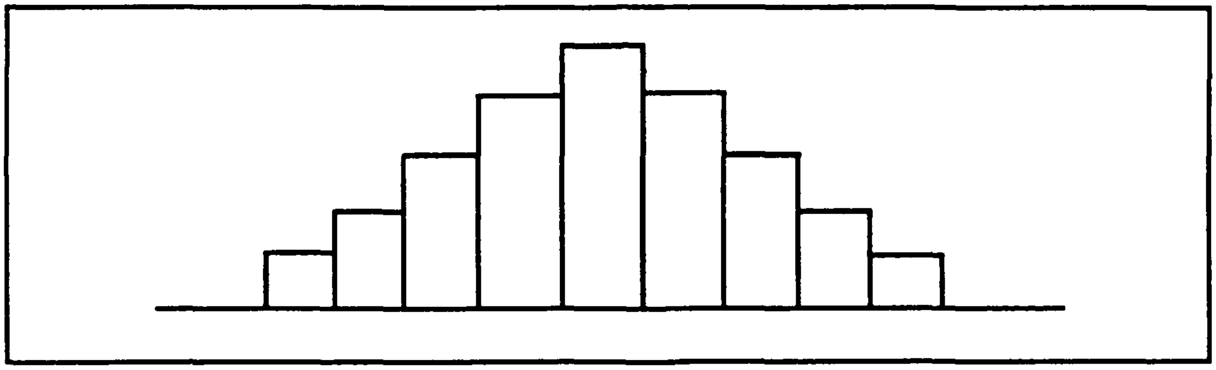

Figure 8-1: Histogram

"Sure," said Newblood, "that's a histogram. You used it to describe the variations in your rod example."

"Right. It's one way of organizing data for analysis. Some information of interest would be the location of the mean and the amount of variation, which should tell you something about its capability to meet your needs. Comparing it to other histograms showing the past performance of the same process can give you some evidence on whether or not it's in control, and comparing, say, data from two suppliers can give you an idea of which provides the better product. This particular histogram shows a normal-like distribution. But suppose it looked like this ..." (See Figure 8-2)

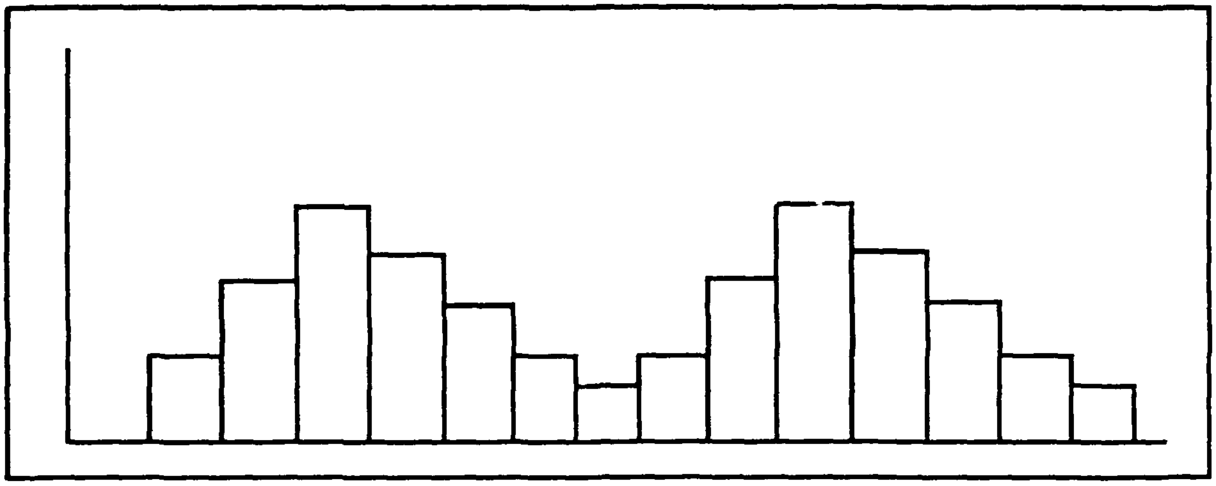

Figure 8-2: Bi-Modal Distribution

"That looks like you plotted two histograms on one chart," said Newblood.

"In effect, I did," Hatt responded. "This is a bi-modal distribution, meaning that there are two central tendencies. What this tells you is that you have some division in your process. It might be two suppliers, or two machines, or two shifts of workers. Whatever the cause, one set is not in tune with the other. Now you have something to look for."

"I can see that, but is this process in or out of control?"

"Could be either. For example, if you had two regular suppliers and both had their processes in control, but at different levels, the combined products would be in control, but with a wider variance than either alone. And every sample would show a bi-modal distribution. But, if you usually have a normal distribution and suddenly get a bi-modal, you know some special cause is at work. An example could be that your supplier put on a new machine that was set wrong, or a new shift that hadn't been trained enough. Whether it's in control or not, a bi-modal distribution shows a definite opportunity for improvement. Now what do you think of this?" (See Figure 8-3)

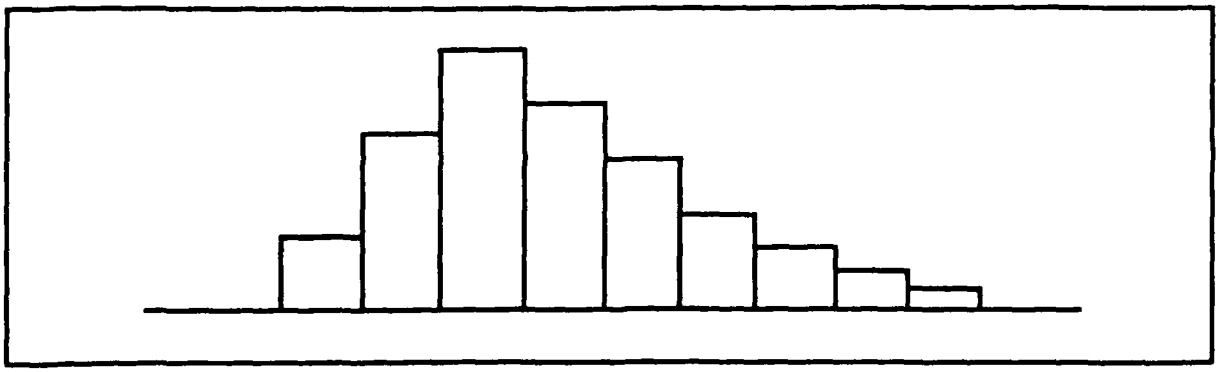

Figure 8-3: Skewed Distribution

"Now that's definitely out of control," declared Newblood.

"Sorry, but maybe not. If you have reason to believe the normal should apply, a skewed distribution is a sure sign of trouble. But it is reasonable to expect some skewed distributions. For example, in diagnosing a failure, there are some tricky failure modes that take a long time to find. Or, if your process is transportation, traffic conditions include an occasional grid lock that would skew a histogram of travel time. One histogram won't show whether or not the process is in control. That's the job of the control charts, though a change in shape from an earlier histogram or a shape that doesn't fit the process does indicate an out of control situation. But don't get hung up on in or out of control. You're trying to analyze the data. When you find skewness, you asked yourself why it happens and what you can do about it. Then you go find more data to test your answers, or maybe, run a test. For example, trying different routes for transporting between two points. When you find a better way, change the process. Then get more data to check the results and to find new improvements."

Hatt paused for a breath and then continued, "there are a couple of variations on a histogram that are also helpful. For example, if you plotted the number of something, defects, express mail, what have you, by days, you have a run chart or trend chart. This will tell you how the number changes with time. It will also show any cyclical tendencies. For example, if the number peaks every Monday, the chart is telling you something."

"Another variation is to plot against some divisions that don't represent a scale. For example, suppose you charted the number of express mail requests against the divisions of the laboratory. This shows you relative numbers and since the order you list the divisions is arbitrary, you can put them in order by the length of the bar. This is called a *Pareto Chart* and looks like this." (See Figure 8-4)

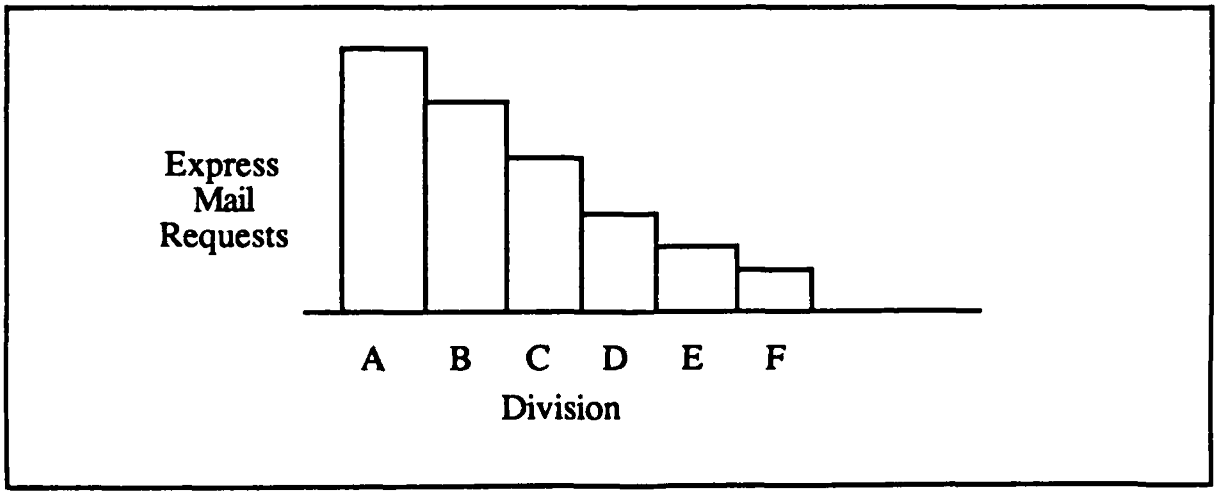

Figure 8-4: Pareto Chart

"With this information, you start asking questions to find out why Division A needs more express mail than B. Maybe they have more projects or more jobs that

need fast answers. Or maybe they need to be trained in more efficient mail procedures. You get more data to answer these questions. But the chart tells you where to look. You often find that 20% of a system causes 80% of its problems. The Pareto Chart isolates that 20%."

Newblood meditated a while, then said, "I can see these charts will help organize data, so I can draw conclusions or at least come up with questions to ask. But I'm still concerned with a step before this. Before I start analyzing data on some variable, how do I know it's one of the drivers of my process. For example, we talked about control charting express mail as a proportion of total mail. It seems logical, but it could be that the number of express mailings is really insensitive to the total amount of mail. Is there a way to check this out before I get too involved with it?"

"Sure is," Hatt replied. "One way is a Scattergram. You just plot points against a vertical scale representing the number of express mailings and the horizontal representing total mailings. So each month, you count the express mail and the total mail and get a point for the chart. After a few months you'll see the pattern. If there is a correlation, it'll look something like this." (See Figure 8-5)

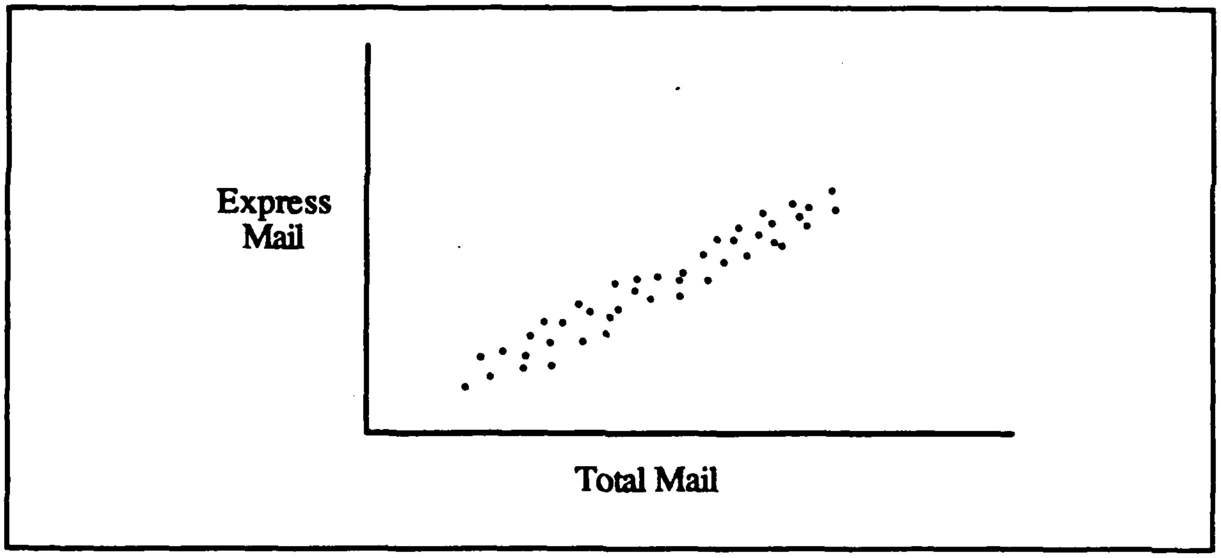

Figure 8-5: Scattergram

You'll get a cloud of dots, but if there is any correlation they'll cluster around a straight line. You can actually draw a line of best fit using what they call a least square method or a regression analysis, but for most purposes your eyeball is enough. The closer the fit of the points to the line, the better the correlation. A fat cloud indicates the correlation is weak, or that other factors involved have a much greater influence. A skinny cloud means a strong relationship, with two exceptions. Here's one." (See Figure 8-6)

Figure 8-6

"What does this tell you?" Hatt asked.

"Seems to say that my express mail stays the same no matter how much total mail I handle."

"Right. In this case you have a remarkable consistency in one variable, but no correlation between the two. The other case where a thin cloud doesn't show correlation is, of course, when the second variable doesn't change much. I suppose you could run into a case where neither varied much and your cloud would look like a dot. In that case you couldn't say you had correlation or not, since neither variable changed. But these are all mavericks. More often a lack of correlation looks like this." (See Figure 8-7)

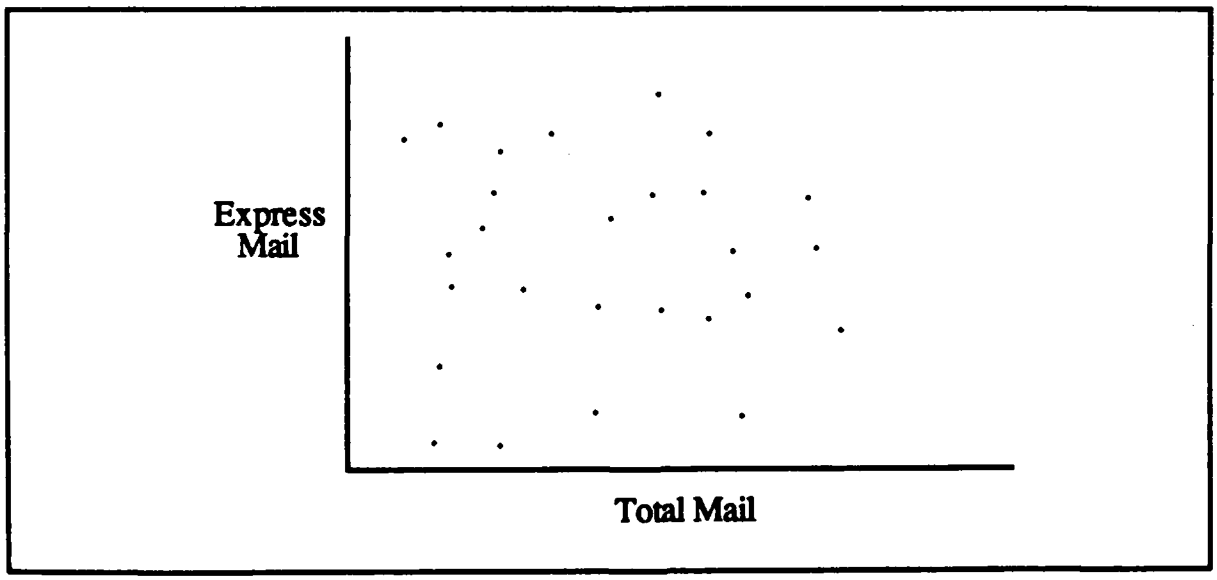

Figure 8-7

"Okay, Hatt, looks useful. What else you got?"

"Well, I think you have all the basic tools. There are some advanced techniques, falling roughly under the heading of statistical design of experiments, but I think you should leave these to the statisticians. Just to give you a feel of them, let's look at a simple example of using data to come up with a robust design, that is, one which is insensitive to variations in the use environment. Let's say you have three variables under your control which you can change at your will. These are your design parameters. Let's use rods again and let these be rod length, diameter, and hardness. You have an application where there are likely to be changes in temperature and load which are use factors you can't control. You can optimize the design for the average temperature and load, but there might be a better way. That would be a way that worked well both under nominal conditions and reasonable variations in use. To find this way you would run some tests. You would select a high and low value for each of the design and use factors and run a test for performance at every possible combination of design and use factors where each parameter could be high, nominal or low. Let's diagram that." (See Figure 8-8)

Test	D1	D2	D3	U1: U2:	N N	L L	H L	L H	H H
1	N	N	N						
2	L	L	L						
3	H	L	L						
4	L	H	L						
5	H	H	L						
6	L	L	H						
7	H	L	H						
8	L	H	H						
9	H	H	H						

Figure 8-8: Experimental Design for Robustness

"I'm calling the Design Parameters D1, D2, and D3, and the use factors U1 and U2. The letter N represents nominal conditions, H is for high and L for low. We run a series of tests at nominal design as the baseline. If the results didn't change significantly with use conditions, we really wouldn't need to go further. But if they do, we want to find a design combination that may not be optimum at nominal use conditions, but is still good and stays good with changes in use. To illustrate, let's say the rods are part of some machine, and our test results are the number of defects produced by the machine in parts per million. Let's fill in some contrived test results." (See Figure 8-9)

	Controllable Variations				Uncontrolled Variations				
	Length	Diameter	Hardness	U1: Temp.	N	L	H	L	H
Test	D1	D2	D3	U2: Load	N	L	L	H	H
1	N	N	N		1.5	2.9	1.9	2.4	2.6
2	L	L	L		3.2	9.0	1.8	1.6	7.8
3	H	L	L		3.1	2.6	2.0	2.3	4.8
4	L	H	L		1.9	2.7	2.0	1.5	3.4
5	H	H	L		2.4	2.2	1.5	1.7	1.9
6	L	L	H		1.6	2.4	1.6	1.5	2.9
7	H	L	H		1.6	1.9	1.7	1.7	1.8
8	L	H	H		3.3	3.3	1.6	1.6	3.3
9	H	H	H		2.2	2.6	1.8	1.6	1.9

Figure 8-9: Illustrative Results

"From this data, we see that if we design to nominal use the variations in the use environment can cause severe changes in the defect rate. A better design might be the one we used in Test 7 where there is a slightly poorer performance at nominal use, but significantly better results over the spectrum of use factors."

"Doesn't look to hard to me," commented Newblood.

"Remember that this is a simple example. The number of tests needed would more than double with every factor you added. So you rapidly get into impractical situations. Statisticians are working on ways to handle these. You may have heard of Professor Genichi Taguchi who is a leader in the area. People like him are invaluable in advancing and using TQM tools. That's why W. Edwards Deming, the top guru for changing our management methods, recommends a trained and experienced statistician be part of every TQM initiation effort. But you have learned a lot, more than enough to make a difference. Go and apply your knowledge."

"Do you mean I've graduated - finally?" grinned Newblood.

"I mean you have enough knowledge to use the basic tools of TQM analysis. But that's a process, too, and I expect you, as a dedicated TQM practitioner, to constantly improve your own processes. Education never ends."

"But my lessons have?"

"Well, no," said Hatt. "As usual, I have some extra words of wisdom. Ever hear of the *Shewhart Cycle*?"

9 THE SHEWHART CYCLE

"*Shewhart Cycle*? How many wheels does that have?"

Hatt shook his head. "Tyrone, you're an incurable wiseacre. For your edification, the Shewhart Cycle describes a method for attacking problems. It was created by Walter A. Shewhart, one of the pioneers in statistical quality control. In Japan, it's known as the Deming Cycle because W. Edwards Deming described it to them. It looks like this" (see Figure 9-1).

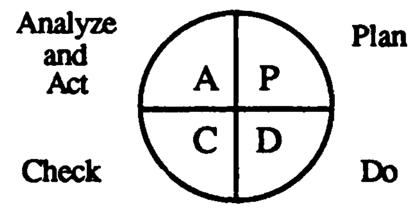

Figure 9-1: Shewart Cycle

"You start with P, which stands for planning. You define the problem you are attacking, decide what data you need and how to get it, and what you will do with it. The process flow charts and Ishikawa diagrams are helpful here. You also identify an appropriate team."

"Then you are ready to do something and that is the D on the chart. This could be getting the data you decided you needed, running a test, making a change, whatever your plan calls for."

"The next step, C on the chart, is to check the results of your action. In some instances, this would be done by a control chart. In any event, you evaluate the results and causes of variation. Histograms, Pareto charts and scattergrams have a place here."

"The last step, A, stands for Analyze and Act. What did the data in step C tell you? Based on that you take appropriate action, which could be a process change or a decision that a new plan is needed. In any event, after you act, you go back to P and start another cycle. Even if the first trip around worked wonders, there are always more opportunities waiting to be discovered. The cycle is really a spiral going upwards to better and better quality."

"And that, my friend," concluded Hatt, "ends your basic training. Are you ready to start changing the world?"

"My part of it anyway," nodded Newblood. "Appreciate the education, and I presume I can call on you if I run into problems getting these tools to work."

"It would be my pleasure."

The meeting ended with a cordial handshake. As Newblood left, Hatt began to go through his mail.

The first item was a request for comments on a proposed command regulation which would require every travel request to include a mandatory comparison of benefits and cost of travel versus the use of vidioteleconferencing (VTC) facilities.

Another example of management by hassle, thought Hatt. He was familiar with the VTC facility. It provided television and graphics communication with similar facilities throughout the command. It was certainly a viable alternative to travelling, he mused. But ...

Letters and telephone calls are substitutes for travel. What controls these? A traveller's manager would not authorize a trip when a letter or phone call would do. The same manager could also consider the possibility of VTC when receiving a travel request.

We have one VTC facility. Even with full time use, it would not make much of a dent in the number of trips we take. We should, of course, take advantage of it. But the proposed requirement adds a burden to every trip request for the possible saving of a relatively small number of trips. The time wasted in analysis is likely worth much more than the possible savings, and we add another annoyance to the work force. *There must be a better way.*

The VTC is a high-tech tool like personal computers. It takes some training before a potential user feels comfortable with it. Many people were slow to use personal computers because they did not want to spend the time required to learn the ropes. The same is probably true with the VTC. The proposed solution will likely produce nothing but grumbling and ingenious excuses for not using the VTC. A better solution would be to mandate an orientation session in the VTC. All new employees should have it, and the current work force should be scheduled in groups starting with the managers. Once familiar with it, more people will want to use it.

Even so, if someone we want to contact does not want to use the VTC, we cannot force him to, no matter how cost effective. Better than requiring cost analysis, the command should see that everyone got familiar with the VTC facility. If the tool has value, the people will use it. If not, it is a lost cause.

Hatt knew the laboratory's VTC was almost in daily use. Yet, he thought, the proposed regulation gives the impression that the VTC is not used much and someone is afraid that its value may be questioned. Better the command should have its workers think someone is trying to help them than that someone is putting more burden on them to justify a project that is not working out.

Hatt picked up the phone and began dialing.

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